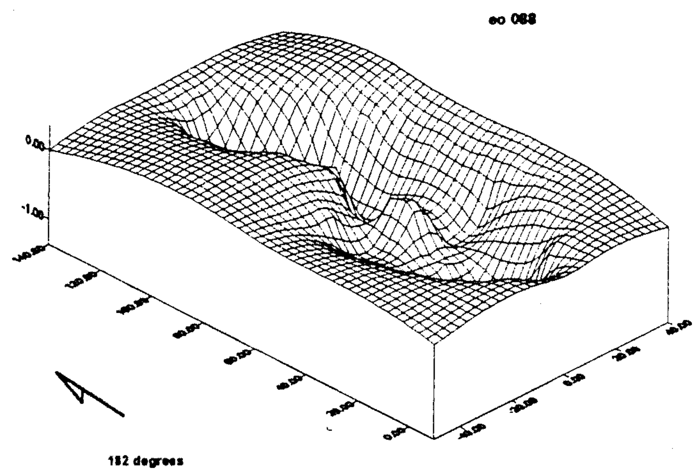
Preliminary Evaluation of Basin Morphometry and Field Chemistry of Montana's *Howellia aquatilis* Ponds



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Introduction

Studies of the ecology and management of *Howellia aquatilis* in the Swan Valley have highlighted pond hydrology as a key factor in meeting the habitat needs of the species (Lesica, 1990; Lesica, 1992). Understanding controls on the hydrologic functioning of *H. aquatilis* ponds requires investigation of water balances and local hydrogeology of a representative sample of ponds. At the same time, the ecology of the species implies an important role for pond morphometry in the response of populations to changing water balances (Shapley and Lesica, 1997). Size, shape and orientation may also be important to other ecological factors such as light regime. Pond geometry is therefore viewed as one important characteristic in selecting a subsample of the more than 100 known inhabited ponds for future investigation. The purpose of this study is to characterize key morphometric and geochemical variables for a large number of occupied ponds, addressing certain components of the 'extensive' data collection suggested by Shapley and Lesica (1997). This broad survey of habitat hydrology will provide an important basis for choosing sites for future site specific studies, studies needed to answer questions regarding source contribution and land management implications.

Study Sites

Howellia aquatilis was known from 101 wetland basins at the time of this survey, spanning the 50-mile length of the Swan River Valley in Lake and Missoula Counties, Montana. During initial field visits timed to coincide with active growth and reproduction (between July 21 and August 11, 1997) specific conductance, pH and temperature data were collected from all known occupied ponds on public land and from ponds on private land where access was permitted (n = 97). Observations on the presence of *Howellia aquatilis* and the invasive grass *Phalaris arundinaceae* were made incidental to this first 1997 visit. Pond water levels were marked for later comparison and determination of water level and specific conductance changes.

A subset of the ponds was chosen for cross-sectional elevation surveys and morphological modeling. These ponds were selected on the basis of three criteria:

1) Distribution among the recognized clusters of *H. aquatilis* occurrences within the Swan Valley;
2) Gross local relief of the immediate pond watershed, based upon 1:24,000 topographic mapping, and
3) Specific conductance of pond waters, measured during a comprehensive survey of known occupied ponds during the first 1997 site visit.

For each recognized cluster of *H. aquatilis* occurrences, ponds representing high and low relief settings and high and low specific conductances (relative to the range displayed by the occurrence cluster) were selected for elevation surveys. (Relief categories were based upon the number of 20 foot contour intervals between the site and adjacent mapped drainage features, i.e., the height of local drainage divides relative to each pond.)

Additional ponds were then chosen by lot from among the remaining occurrences in the cluster, up to a total approximately representative of the cluster's contribution to the total set of Swan Valley occurrences of *H. aquatilis*. The proportionality among clusters is only approximate, as the time necessary for surveying individual ponds varied widely and was difficult to predict *a priori*. Thirty-five occupied sites were selected through this process. One site selected was an unusually large wetland that could not be effectively surveyed with the procedures used. Deep water prevented the completion of cross sections at three Condon Creek sites, resulting in under-representation of the Condon Creek cluster. At the remaining 31 ponds, two to four elevation cross-sections were completed.

Methods

Temperature, pH and specific conductance measurements were collected using one or more of three field instruments: an Extech Oyster meter with combined pH/conductivity electrode, an Orion Model 124 conductivity/temperature meter, and an Oakton Instruments pen-style pH meter. The Extech instrument was calibrated to multiple pH buffers on several occasions daily while in use. The performance of the Orion probe was checked against conductivity standards prior to each use. Under humid conditions the Orion unit performed erratically, and only the Extech instrument was used for specific conductance measurements. Agreement between the two pH meters was generally within 0.1 units. Where agreement was poorer, data tables present measurement from the calibrated (Extech) instrument.

We measured relative elevations along surveyed cross-sections using a tripod-mounted surveying level and stadia rod provided by the Flathead National Forest. We measured linear distances with a 30 meter nylon tape. We measured elevations at intervals ranging from <1 meter to 10 meters, depending on pond size and pond-bottom relief. Stadia rod positions were usually reached on foot; on several occasions deep water required the use of either a kayak or an extender attached to the rod to complete cross - sections. The elevation of the water surface and of features indicative of full-pool elevation were noted along each cross - section. Compass bearings of cross sections and other significant landmarks are based on measurements made with a hand-held Brunton compass. Elevation surveys were carried out from August 27 to September 10, 1997, a schedule planned to coincide with seasonally low water levels and curtailed growth and reproduction of *H. aquatilis*. However, high 1997 water levels meant that many ponds remained far above minimum water levels during these surveys, complicating measurements and preventing the completion of some cross-sections.

At each site, one cross-section followed the major axis of the pond. Additional sections were measured along transverse axes. For ponds with complex forms, we measured as many as two additional sections determined by pond geometry. We also attempted to map pond perimeters using a global positioning system (GPS), but found signal reception to be very poor at many sites due to dense forest canopy cover.

Therefore, perimeter locations are based on the cross-section positions and occasional point measurements accompanied by aerial photos and field sketches of pond outlines. During these surveys, we examined pond perimeters for evidence of surface water inflow or outflow, and remeasured the pH, specific conductance and temperature of pond waters. The distribution of *H. aquatilis* and other aquatic plants along the surveyed cross-sections was noted qualitatively.

Most elevations could be read with a precision of $\pm$ .015 m or better, and elevations of the water surface are usually replicated within .01 m on a given cross section. However, tussocky vegetation, soft substrate and deep water substantially decreased the accuracy of many measurements. The position of full-pool features (shorelines and vegetation transitions) is a matter of judgment, and elevations of such interpreted features may differ by as much as .1 to .2 meters within a given pond. Compass bearings are probably accurate only to $\pm$ 2-3 degrees, and taped distances may contain errors as large as $\pm$3% of taped distance due to interference by vegetation. The map positions of pond boundaries are based on a limited number of field measurements and in some instances are quite generalized. Overall, these data are sufficient for their intended screening and classification purposes but do not provide highly detailed topographic definition to the ponds.

Data Processing and Pond Models

Using the surface-plotting package SURFER (Golden Software, Inc., 1994), a kriging routine translated the elevation cross-sections and boundary positions into interpolated three dimensional models of the individual ponds. I then used the 3-D grids to calculate changes in wetted pond surface area (a measure of potential germination area) and pond volume (a measure of pond water balance) with change in the elevation of the modeled pond surface. The pond model output was then imported to the graphical plotting package GRAPHER (Golden Software, Inc., 1993) and displayed as stage/area and stage/volume response curves characteristic of the modeled geometry of the individual pond. The stage/surface area curves are a graphical representation of surface exposure with change in water level and can provide the basis for categorizing morphometric pond types. Stage/volume curves (not presented here) represent water storage within the modeled pond and may be used in conjunction with measured catchment areas to examine questions of pond water balance.

Discussion

Visual inspection of the interpolated pond grids shows considerable variation in basin shape and complexity. Figure 1 shows a selection of simple, nearly equidimensional pond models and their stage/area response curves. Ponds in this figure are shown at different scales; hypsometric response curves are at a common scale and show the contrast in pond size as maximum values along the area (horizontal) axes. Ponds of this general map pattern (ratio of major to minor axes ≤ 1.5) are classified as 'equi' in Table 1.

Figure 2 shows a selection of elongate pond models with length to width ratios greater than 2, again shown with stage/area response curves. More complex pond model forms represent ponds with multiple basins, moat - like ponds with a central elevation maximum, ponds with lobate outlines, and one pond with an upland island within the wetland perimeter (Figure 3). In the latter set, Table 1 distinguishes between 'irregular' ponds (having complex outline but a single principal basin) from 'complex' ponds with multiple basins forming separate ponds under low - water conditions.

The pond models reflect interpolated depths based on SURFER's kriging routine, so measured depths at cross-section data points are not preserved exactly in the 3-D mesh. Basin shape and depth along measured cross-sections is reasonably well preserved, however. Artifacts of the kriging process are visible in many of the pond models, especially where there is uncertainty in the interpretation of the maximum pond water level. Upland areas above the interpreted full pool elevation are given artificial elevations of 0 meters to clarify the plotting of the model basins, therefore no reality should be ascribed to the "plateaus" surrounding the model basins.

Figure 4 shows a composite plot of the depth - area curves for all 31 modeled ponds. This figure summarizes several basic pieces of information resulting from the pond surveys. Maximum model depths at full pool range from .5 m to 2.2 m, with a modal value near 1 m. Area of model "substrate" flooded at full pool ranges from less than 1000 m^2 to almost 13000 m^2. Overall steepness of the modeled pond bottom is represented by the average slope of the stage/area response curves. There is a visually apparent correlation between maximum flooded area and gradient of the substrate. Larger models (and ponds) have generally low gradients relative to smaller ponds. The two model ponds with the largest amplitude (EO 062 and EO 083) represent sites occupying relatively deep basins with topographic spill points well above the usual range in water levels.

Statistical analyses of these curves are beyond the scope of this data collection project, but inspection of Figure 4 suggests that there are four geometric pond types in the surveyed population which can be defined by their hypsometric response functions. These four types should be represented in any set of sites chosen for analysis of the influence of groundwater or of the ecological effects of water balance change. Figures 5 through 8 show these modes of model geometry plotted with their corresponding element

occurrence numbers. Small, relatively steep geometries form the largest apparent cluster, identified as hypsometric class 1 in Table 1. Large, low gradient sites constitute another apparent mode (hypsometric class 3). Three relatively deep models of intermediate size and slope also stand out, and are designated class 2 in Table 1. Finally, the deep, high-amplitude basins discussed above form a distinct grouping, referred to in Table 1 as hypsometric class 4.

Arduously collected field observations (the 'wader penetration factor') indicate that the large, low-gradient ponds have greater accumulations of organic sediment than most of the smaller ponds. In some cases more than a meter of peat underlies the central region of larger ponds, typically with *H. aquatilis* occurring along pond margins in slightly deeper, less infilled pools or 'moats'. Survey elevations (and pond models) reflect this peaty surface. Pond contours and hydrologic response of these ponds would probably change with negative water balance changes, as organic sediments experienced greater surface oxidation.

Table 1 shows specific conductance data for all sites visited twice during the 1997 field season; Table 2 summarizes geochemical measurements for all ponds inventoried during 1997. Consistent with the results of Lesica (1992), specific conductance of the ponds varied from < 30 μS/cm to 400 μS/cm, with most ponds below 150 μS/cm (Figure 9). Measured pH ranged from 6.2 to 7.8, with most measurements between 6.5 and 7.5. pH is diurnally variable in dilute surface waters supporting photosynthetic activity. Since collecting measurements at a consistent time of day was not possible for this survey, little can be said regarding pond pH beyond the fact that the ponds do not depart very far from neutrality and that there is a general correlation between values of pH and specific conductance. Of the 34 ponds with early and late season specific conductance measurements in 1997, only five showed apparently significant increases in concentration, despite consistent reductions in pond volumes. Several ponds showed substantial declines in specific conductance with declining volume, while most remained unchanged within the probable precision of our field measurements. Above - average precipitation during the summer of 1997, plant uptake of solutes, groundwater outflow, or perhaps (in the most concentrated ponds) carbonate equilibria are possible explanations for this general lack of evaporative concentration with declining pond volume.

Most *H. aquatilis* ponds have been considered topographically closed under present climatic conditions (Shapley and Lesica, 1997). Careful observation of the 34 surveyed ponds showed that at least 12 have spill points occupied frequently enough to maintain some channel morphology. Outlet elevation control of pond hydroperiod and interpond exchange of surface water during wet periods thus appears to be more common than previously supposed.

This project provided a broad sampling of pond morphomotry and defined variability significant to the expected interaction of *H. aquatilis* and hydrologic units of the species Montana habitat. Further analyses of pond morphometry should relate pond basin data to catchment size and topographic relief, likely to be important controls on shallow groundwater gradients and water balance dynamics. Water chemistry is generally dilute but displays a range of solute concentration that may reflect differential ground-water relations, therefore site selection for detailed hydrologic analysis should include measures of water chemistry. The presence of pond outflow channels is a measure of basin water balance and water level stability and should be retained as a screening criterion for study site selection. The role of pond size and orientation on light regime should be evaluated with respect to management of adjoining lands.

Acknowledgments

Jim Vanderhorst of the Montana Natural Heritage Program conducted all early-season observations and was an indispensable collaborator in the morphometric pond surveys. Maria Mantas of the Flathead National Forest provided indispensable support and arranged for use of surveying equipment. Ann Dahl and the Swan Ecosystem Center provided very helpful logistical support. John Hinshaw of the Montana Natural Heritage Program and Don Mittlestadt of the Montana Department of Environmental Quality provided technical assistance with GPS. Steve Shelly of USFS Region 1 and Peter Lesica, Conservation Biology Research, each provided valuable conceptual inspiration.

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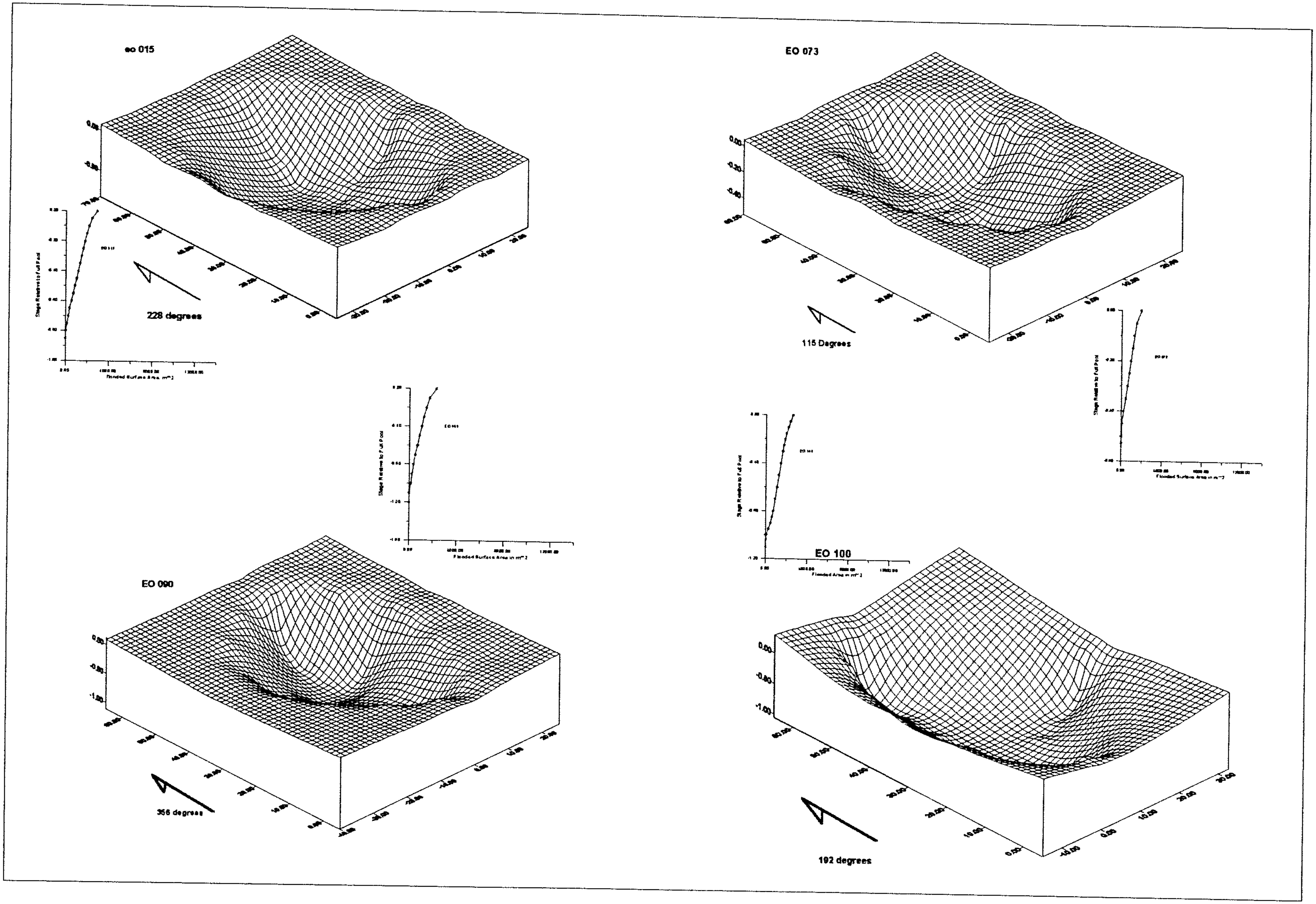

Figure 1. Selected equidemensional ponds.

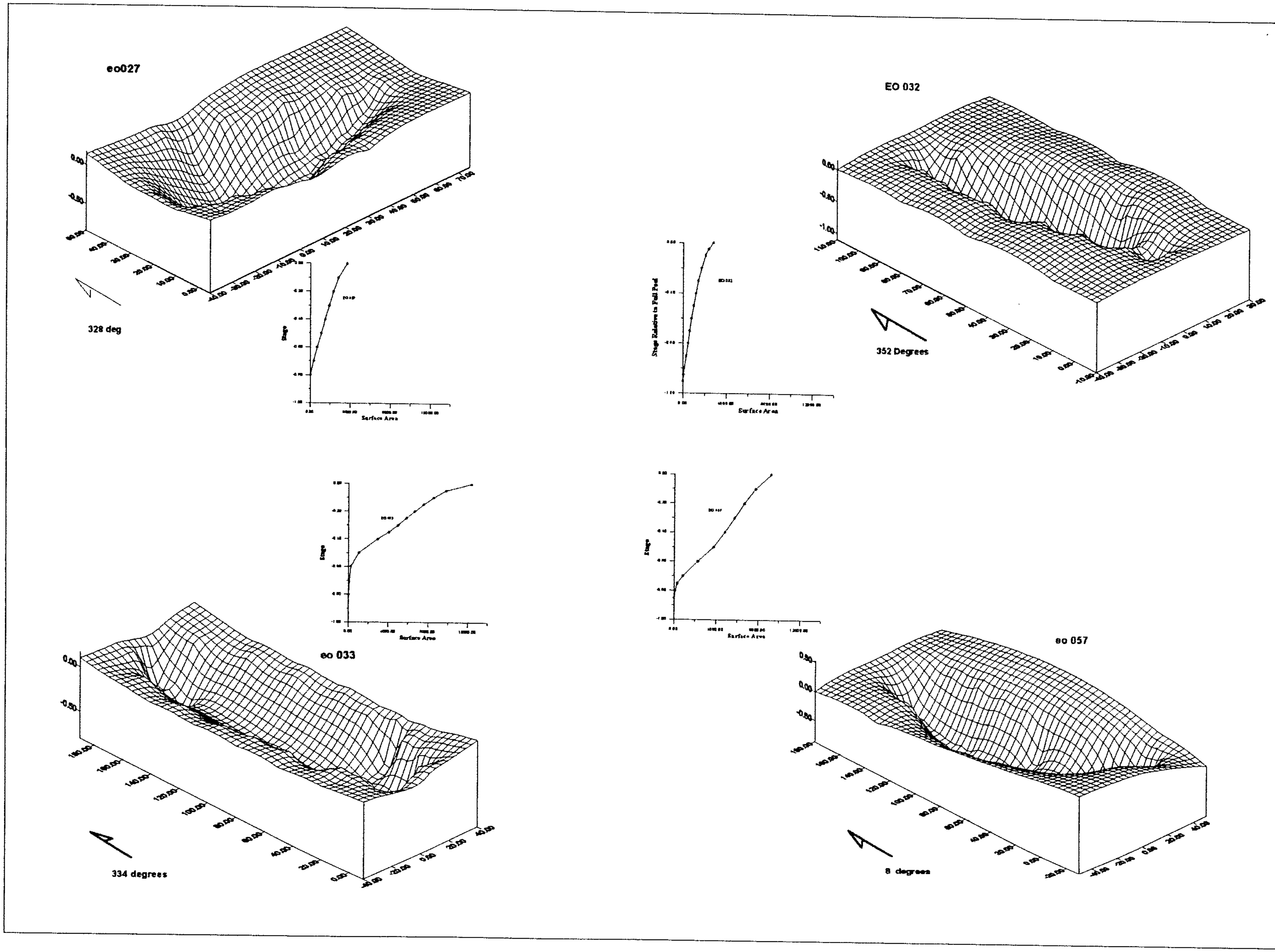

Figure 2. Selected elongate pond models.

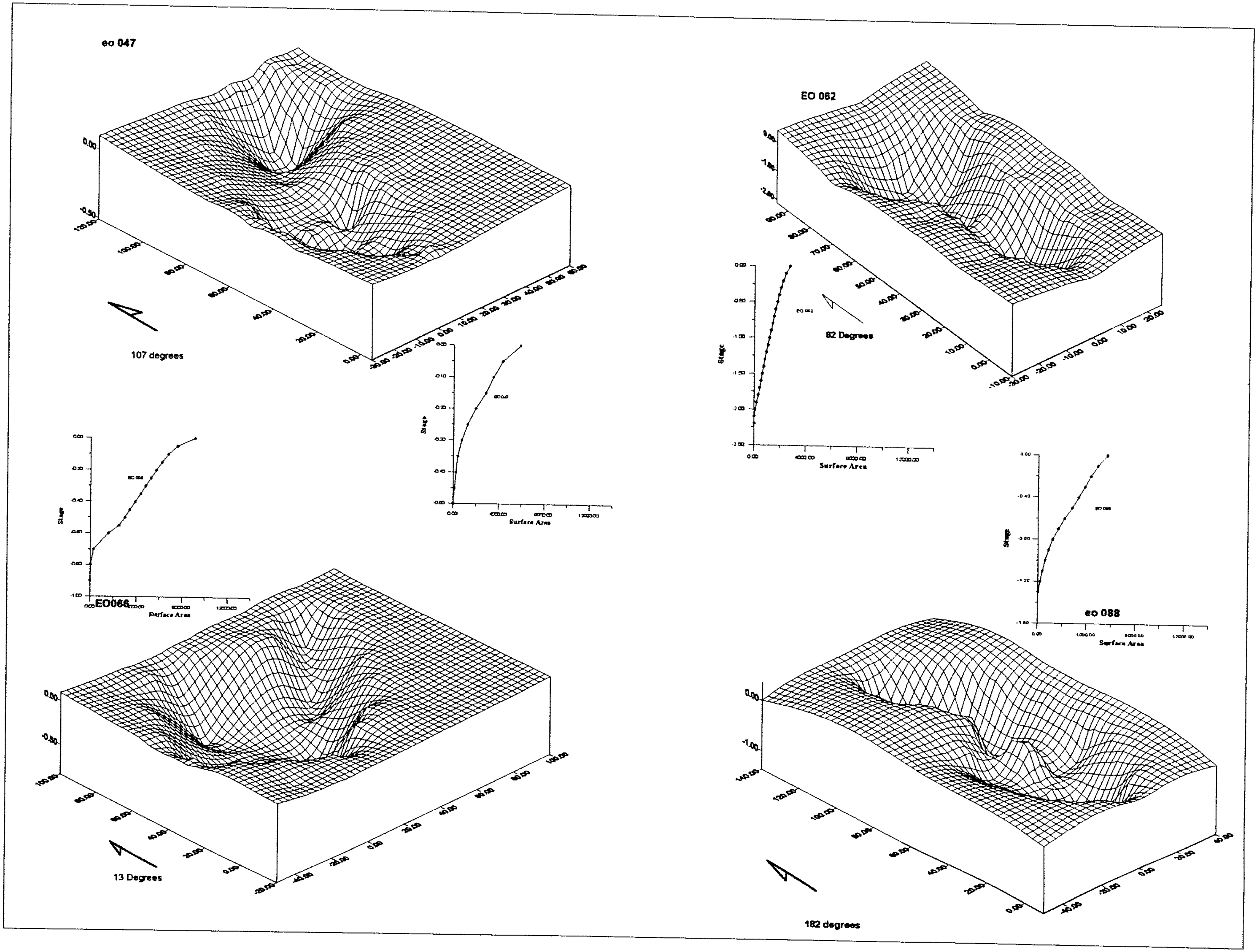

Figure 3. Complex pond models.

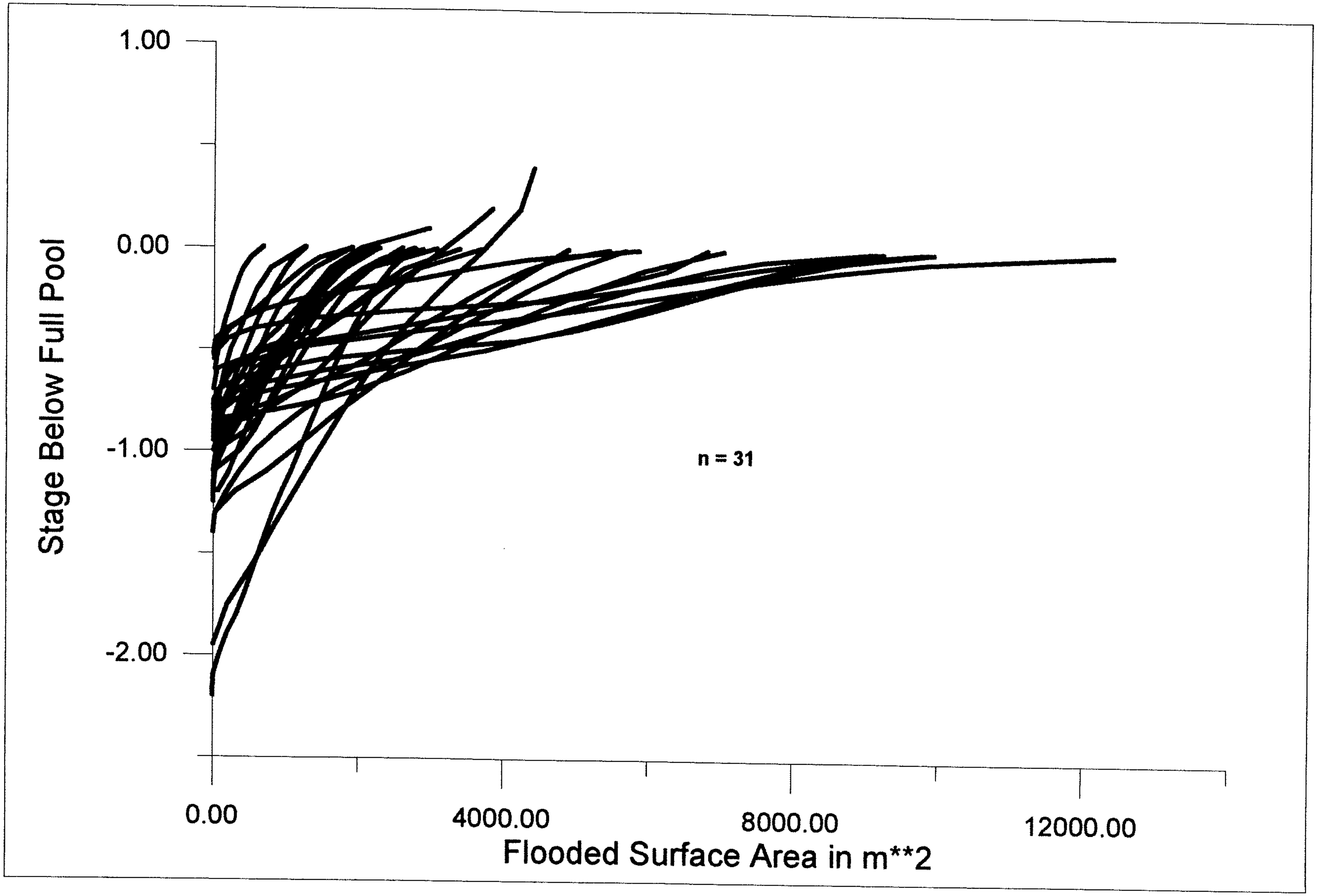

Figure 4. Hypsometric response curves for 31 surveyed ponds.

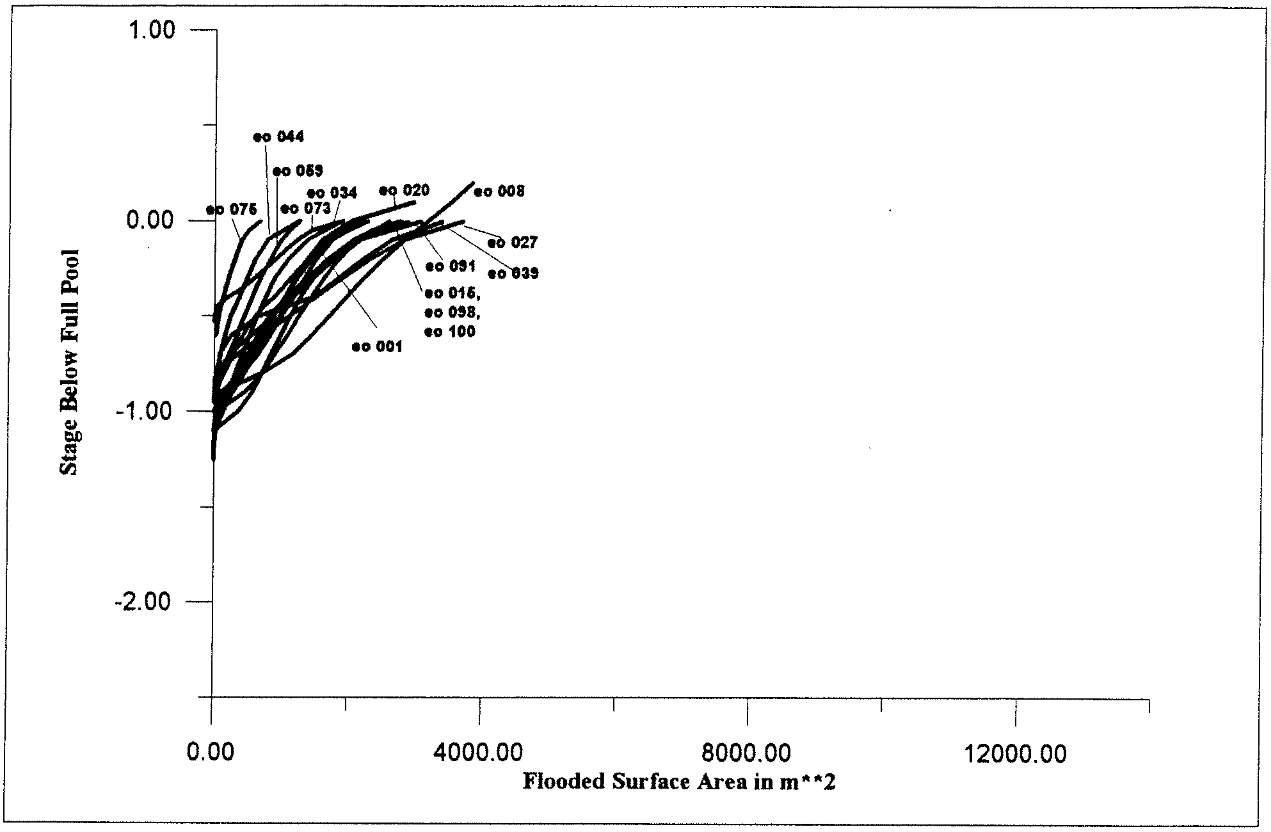

Figure 5. Hypsometric response class 1.

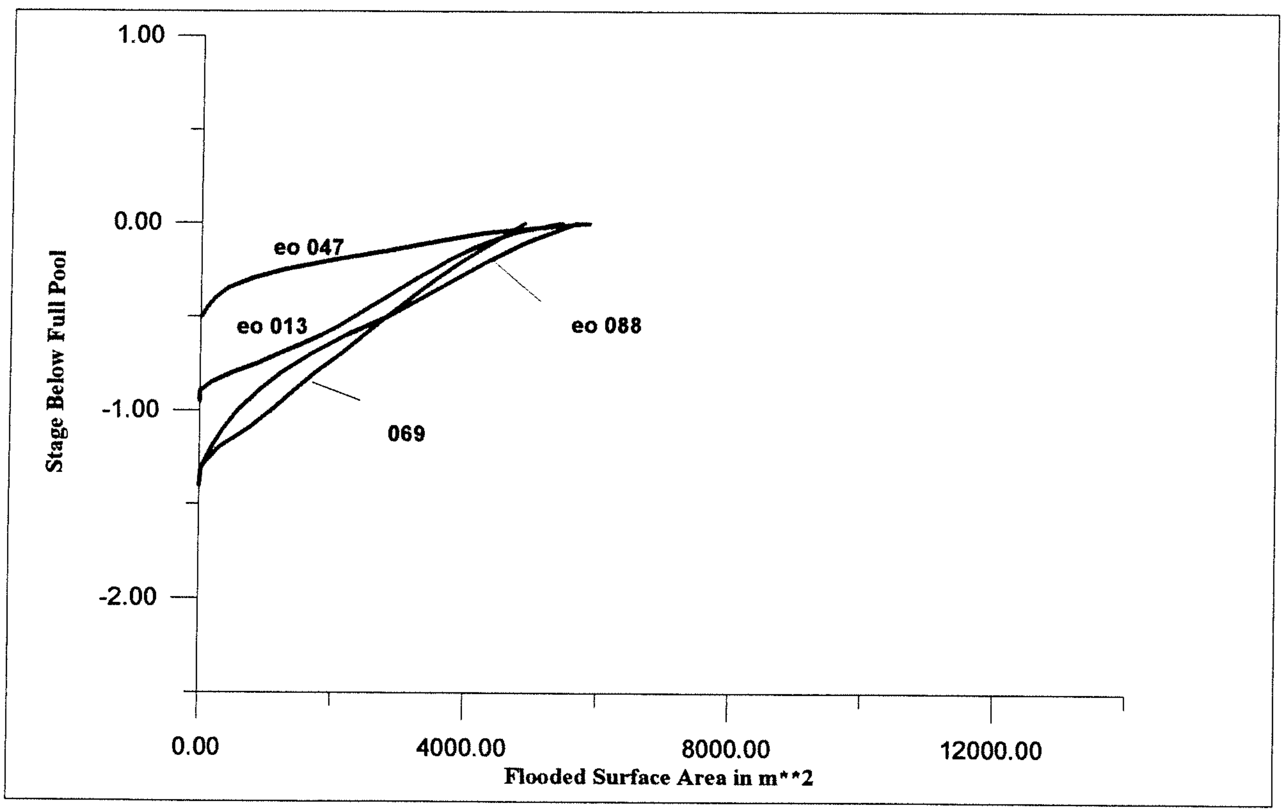

Figure 6. Hypsometric response class 2.

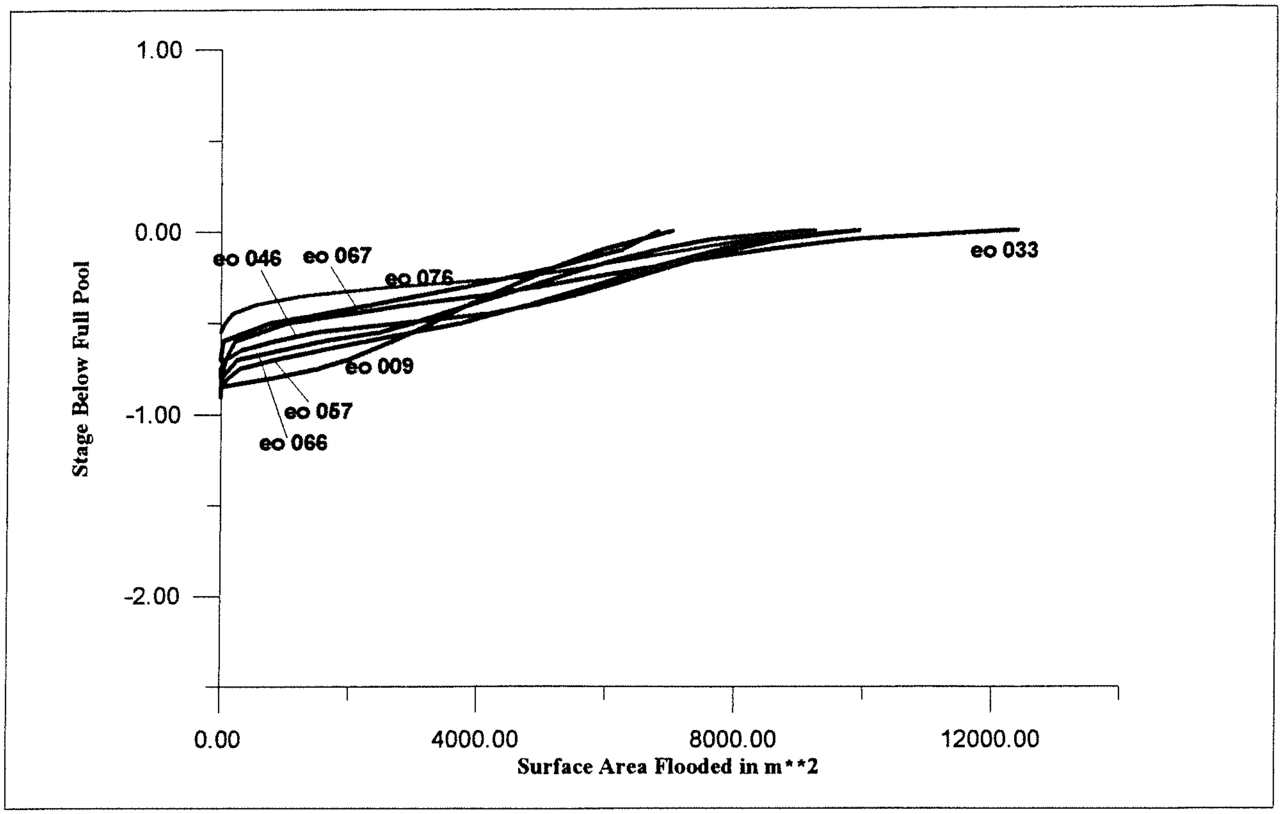

Figure 7. Hypsometric response class 3.

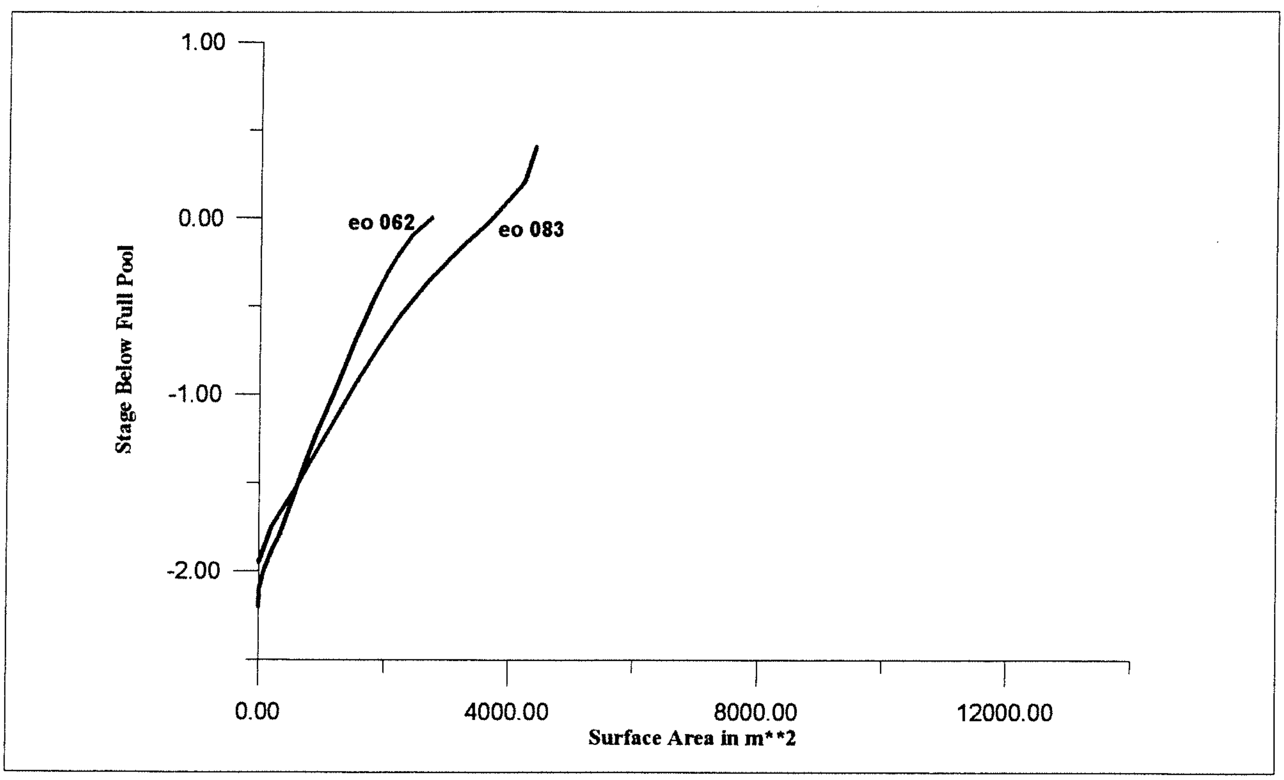

Figure 8. Hypsometric response class 4.

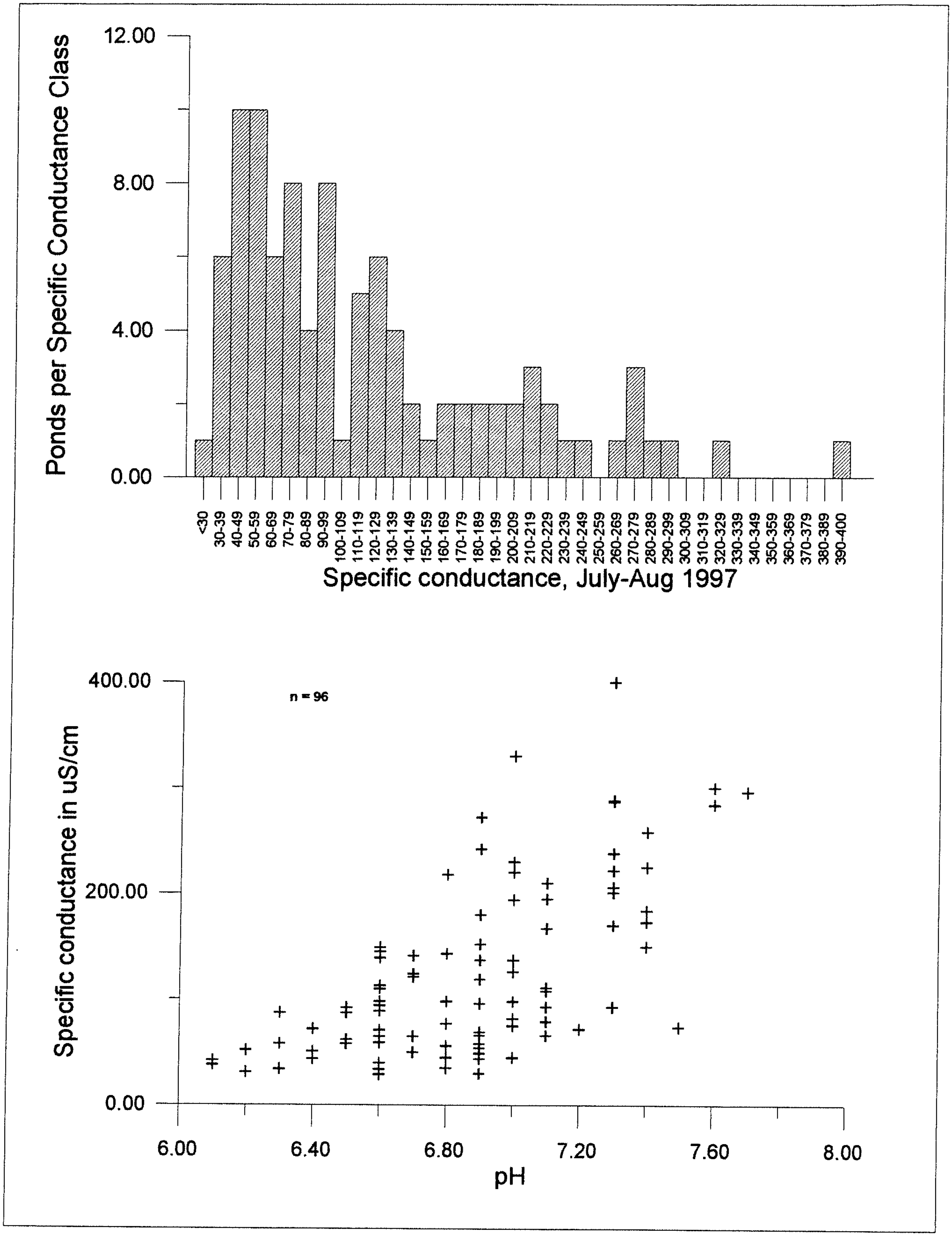

Figure 9. Specific conductance and pH of pond waters, July and August 1997.

eo #	Site Cluster	Maj azimuth	Axial ratio	Full pool area, m**2	Full pool depth, m	Full pool vol, m**3	Outlet stream	Basin form class	Hypso. class	Spec. cond. (early/late) mS/cm	Δ spec. cond. (late - early) mS/cm
001	Lindbergh Lk	350	1.49	2211	1.04	978	N	equi	1	63/47	+16
008	Cilly Creek	45	1.16	3159	1	2317	Y	equi	1	284/295	-11
009	Cilly Creek	30	1.33	7026	0.85	3145	N	complex	3	238/249	+11
013	Cilly Creek	297	1.67	5446	0.92	2242	Y	elongate	2	149/123	-26
015	Cilly Creek	48	1.15	2875	0.83	957	N	equi	1	92/**	**
020	Condon Creek	336	1.72	2029	1.05	1164	Y	elongate	1	75/79	+4
027	Condon Creek	60	2.4	3685	0.84	1243	N	elongate	1	206/263	+57
032	Lindbergh Lk	352	4	2764	1.1	1079	N	elongate	1	119/106	-13
033	Lindbergh Lk	334	2.98	12397	0.8	2995	N	elongate	3	143/125	-18
034	Lindbergh Lk	335	1.37	1895	1.12	717	Y	irregular	1	77/68	-9
039	Lindbergh Lk	85	1.22	3382	0.77	1073	N	complex	1	58/48	-10
044	Lindbergh Lk	310	4.14	1247	0.95	333	Y	elongate	1	58/40	-18
046	Lindbergh Lk	305	1.86	9929	0.78	3426	N	complex	3	69/60	-9
047	Lindbergh Lk	300	2.6	5851	0.51	903	N	complex	2	113/100	-13
057	Cilly Creek	8	3.18	9232	0.87	3636	Y	elongate	3	288/210	-78
059	Piper Creek	85	2.7	1260	0.91	470	N	elongate	1	50/40	-10
062	Piper Creek	82	2.12	2742	2.11	2430	N	complex	4	44/37	-7
066	Glacier/Kraft	33	1.29	9136	0.84	3021	N	irregular	3	45/40	-5
067	Glacier/Kraft	36	2.02	6803	0.67	2236	Y	elongate	3	42/66	+24
069	Glacier/Kraft	4	2.9	4876	1.32	3007	Y	elongate	2	49/40	-9
073	Holland Lake	295	1.51	1902	0.53	374	Y	equi	1	124/123	-1
075	Holland Lake	342	4.81	673	0.7	142	N	elongate	1	180/**	**
076	Holland Lake	313	1.54	9837	0.58	2094	N	complex	3	51/93	+42
083	Holland Lake	57	2.33	3719	1.96	4723	N	elongate	4	87/117	+30
087	Glacier/Kraft	30	1.05	2265	1.26	1088	Y	irregular	1	220/190	-30
088	Glacier/Kraft	2	2.08	5666	1.37	2606	N	complex	2	137/120	-17
090	Piper Creek	356	1.21	2275	1.11	925	Y	equi	1	170/162	-8
091	Piper Creek	52	1.88	3065	1.12	1257	N	elongate	1	82/73	-9
095	Piper Creek	42	1.75	2149	0.93	751	N	complex	1	150/143	-7
098	Piper Creek	20	6.9	2732	1.18	1002	N	elongate	1	111/93	-18
100	Piper Creek	12	1.49	2589	1.05	1276	N	equi	1	93/**	**

Table 1. Summary data from pond surveys and basin models.

eo	pH	Spec Cond	Date	Howellia	Exotics
1	6.8	56	8 2	2 w/fr. + frag. @ S end	
2	na	78	8 3	frag. w/ seed in open water near logs	CIRARV edge
3	6.8	98	8 8	<10 w/ emerg. fr.	
4	6.6	113	8 8	none found; deepest unsurveyed	
5	6.9	242	7 21	none found; incomplete survey	PHAARU @ oxbows
6	6.6	29	7 29	present w/submerg. + emerg. fl.	
7	6.6	71	7 28	50+ w/ emerg. fl+submerg. fr. in open water @ N si	PHAARU @ W end
8	7.6	284	7 28	present w/submerg. fl.	
9	7.3	238	7 28	few w/submerg. fl. among Equisetum	
10	7.3	287	7 28	few w/submerg+ fr.	
11	7.3	222	7 24	many frag., few rooted among logs @ NW end	
12	7.3	201	7 24	few w/ submerg. fl. among Carex @ N end	CIRARV nearby
13	6.6	149	7 24	abundant w/ emerg. fl. in open water + betw. Carex	
14	7	137	7 24	present w/ fr. + emerg. fl. among CARVES	
15	6.5	92	7 24	50+ emerg. fl. @ open water center	
16	6.8	218	7 28	50+ scattered in open spots w/ emerg. fl., sub. fr.	
17	6.3	87	7 28	none found; little open water habitat	
18	6.2	52	7 29	few plants w/ fr. among dense Equisetum	PHAARU @ NW end
19	7	330	7 29	none found; incomplete survey	
20	7	75	7 19	present w/submerg. fl.	
21	6.4	44	7 19	none found	CIRARV, TYPLAT
22	6.9	66	7 19	none found	
23	6.9	54	7 19	present w/ emerg. fl.	
24	6.9	58	7 19	none found	
25	6.9	44	7 19	none found	PHAARU on logged side
26	6.9	96	7 19	present w/ submerg. fl.	
27	7.3	206	7 19	present w/ submerg. fl.	PHAARU @ NW end
28	7.6	300	7 19	none found	
29	7.7	296	7 19	present w/ submerg. fl.	CIRARV @ N side
30	6.8	56	7 18	present w/ emerg. fl.	
31	7.4	225	7 19	none found	PHAARU @ S side
32	6.9	119	8 8	30 w/emerg. fl+fr. on edge of open water	TYPLAT w/ HOWAQU
33	6.8	143	8 8	few plants w/ fr. in open water moat @ S tip	
34	6.8	77	8 8	few plants w/ emerg. fr. among sparse CARVES	
35	6.1	38	8 8	50 plants w/ emerg. fl. + fr.	algae bloom
36	6.6	139	8 2	20 plants scattered in open water @ SW side	
37	6.6	145	8 3	small plants w/ fr. among emergents @ S end	
38	6.5	62	8 3	2 plants w/ emerg. fl. + fr. in open water nr S shore	

Table 2. Field pH and specific conductance of the inventoried ponds.

eo	pH	Spec. Cond	Date	Howellia	Exotics
39	6.3	58	8 3	20 plants w/ emerg. fl. + fr. in open water @ N side	
40	6.6	59	8 3	none found; most of pond surveyed	
41	na	na			
42	na	na			
43	6.6	65	8 2	none found; deepest not surveyed	
44	6.5	58	8 2	3 plants w/ submerg. fr. on edge of open water	
45	7.3	93	8 4	50+ w/ emerg. fl. @ S shore + frag.	PHAARU in middle
46	6.9	69	8 4	none found; survey confined to edges	
47	6.6	113	8 4	none found	
48	7	126	8 4	20 w/ emerg. fl. in deep open water	
49	7	98	8 8	50 w/emerg. fl. + fr. in open water @w + S ends	
50	na	na			
51	6.2	31	8 4	20 w/emerg. fl. in open water center in Sium	
52	6.3	34	8 11	<20 plants w/ emerg. + subm. fr. in Typha @ N end	
53	7.1	79	7 22	few w/ submerg. fr. @ W side + N end	PHAARU @ N end+E side
54	7.1	195	7 31	50+ w/ fr. in open water + in CARVES	
55	6.9	152	7 31	fragments along S shore	
56	6.6	40	8 3	<10 plants w/emerg. fr. @ S end in Sium	
57	7.3	288	7 28	none found on edges; deep center not surveyed	
58	na	na			
59	6.7	50	7 23	none found; deep water not surveyed	
60	7	45	7 23	20 w/ emerg. fl. mostly in bay on S side	
61	6.8	45	7 23	20 w/ emerg. fl. in open water with Sium	
62	6.9	44	7 23	none found; deep water not surveyed	
63	6.6	34	7 30	none found; all but deepest searched	
64	6.1	42	7 30	few plants w/ emerg. fl. + fr. in open deep water	
65	6.9	30	7 30	none found along S shore	
66	7	45	7 30	few plants w/ fr. among heavy POTGRA @ S end	
67	6.1	42	7 30	fragments w/ fr. In open water @ N + S ends	
68	6.8	35	7 30	50 w/emerg. fl.+fr. @ S side in open water	
69	6.9	49	7 30	none found along margins	
70	7.5	74	7 18	few submerg.	
71	6.6	110	7 24	<10 w/ submerg. fr. + emerg. fl. @ N end	
72	7	230	8 4	present w/ emerg. fl.	PHAARU
73	6.7	124	7 24	20+ on shaded edge + with Equisetum; center unsurveyed	
74	6.6	94	7 24	few w/ emerg. fl. in shade @ NE side	
75	6.9	180	7 24	< 20 w/ emerg. fl. across N 2/3 of pond	
76	6.4	51	7 24	abundant in Carex on N side	PHAARU on E side

Table 2. Field pH and specific conductance of the inventoried ponds.

eo	pH	Spec. Cond	Date	Howellia	Exotics
77	6.9	272	8 1	20+ w/ fr. in sparse CARVES + shaded W end	
78	6.6	98	8 1	fragments in pond center	
79	6.7	121	7 25	fragments w/ fr. in bay on S end	
80	6.7	141	7 25	none found; center unsurveyed	
81	7.4	258	7 24	20+ w/ emerg. fl. in open water of sidearm	
82	7.1	210	7 24	20+ in open water; incompletely surveyed	
83	6.5	87	7 24	none found	
84	7.3	400	7 25	1 plant w/ emerg. fl.	PHAARU; hvy algae bloo
85	6.7	65	7 31	few frag. w/ fr.	
86	7	194	7 31	20 w/ emerg. fl. @ E side; frag. @ W side	
87	7	220	7 31	50 w/ emerg. fl. @ E side in sparse CARVES, EQUFLU	
88	6.9	137	7 31	none found; deepest unsurveyed	
89	7.1	167	7 31	100 frag. w/ emerg. fl. + fr.; none rooted	mod. algae bloom
90	7.3	170	7 22	none found; deepest unsurveyed	
91	7	82	7 22	few w/ submerg. fl. @ open water in Sium	
92	7.2	72	7 22	none found; deepest unsurveyed	
93	7.1	66	7 23	<50 w/ emerg. + submerg. fl.	
94	6.6	89	7 23	none found; deepest unsurveyed	
95	7.4	150	7 23	none found in complete survey	
96	7.4	173	7 23	none found; most of pond surveyed	
97	7.4	184	7 23	none found in complete survey	
98	7.1	111	7 23	several w/ submerg. fl. among logs @ S end	
99	7.1	108	7 22	few w/ submerg. fl. @ W side open water in Sium	CIRARV nearby
100	7.1	93	7 22	abundant w/ emerg fl. + submerg. immat. fr.	
101	6.4	72	7 22	abundant w/ submerg. + emerg. fl.	
102	6.6	52.2	7 21	10 w/ submerg. + emerg. fl. @ N+S sides	
103	6.3	23.8	7 21	<50 w/ emerg. + submerg. fl. @ S end among logs	
104	7.2	203	7 28	100+ w/ emerg. fl.	
105	6.3	31.5	8 1	50+ w/ emerg. fl. + fr.; sparse @ E+W sides	

Table 2. Field pH and specific conductance of the inventoried ponds.